Internet Architecture II

EECS 122: Lecture 3

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Today's Outline

- Administrivia
- Last lecture we focused on protocols and layering
- Today, let's begin talking about performance
  - The internet as a network of Queues
  - The components of delay
  - Little's Law
  - Throughput
  - Measuring performance

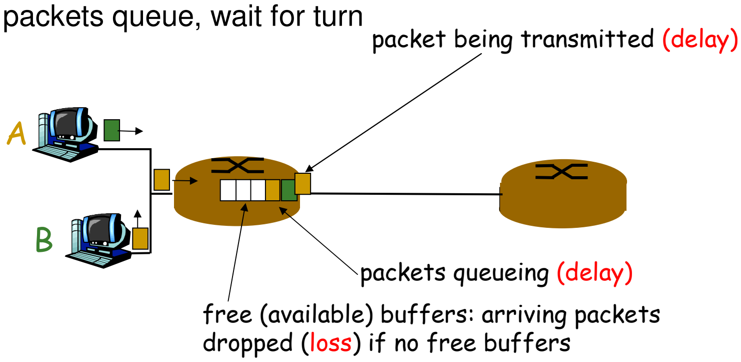
Why care about performance

- The internet is a datagram network with only "best effort" service
- If "best effort" is lousy the network will be useless
  - Remember the World Wide Wait?
- Some applications such as video are quite performance sensitive
- Can't understand the behavior of a network without some understanding of how it performs

How do loss and delay occur?

packets *queue* in router buffers

- packet arrival rate to link exceeds output link capacity
- this often happens because arrivals are random and bursty
- packets queue, wait for turn

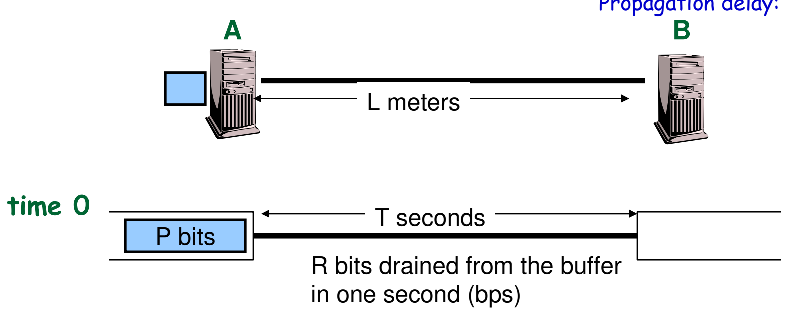


Packet loss

- queue (aka buffer) preceding link in buffer has finite capacity
- when packet arrives to full queue, packet is dropped (aka lost)
- lost packet may be retransmitted by previous node, by source end system, or not retransmitted at all

One packet, One Link

Packet Size: P bits
Bandwidth: R bps
Propagation delay: T sec



At what time is the sending buffer empty? P/R : Packet Xmission Delay
does the first bit get delivered?: T : Propagation Delay
does the last bit get delivered?: T+P/R: Arrival time at B

Propagation Delay, T

Packet Size: P bits
Bandwidth: R bps
Link Length: L meters

- Given P, R and L can you determine/approximate T?
  - No!
- S: speed of the underlying medium
  L: length of the link
  T= L/S

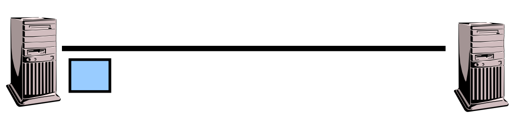
1/speed = 3.3 usec in free space
4 usec in copper
5 usec in fiber

One Packet, One Link

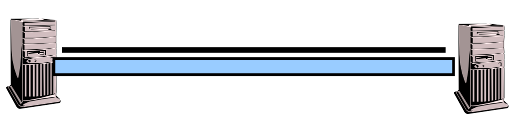
Packet Size: P bits
Link Speed/Bandwidth: R bps
Propagation delay: T sec

At what time is the sending buffer empty? P/R : Packet Xmission Time
does the first bit get delivered?: T : Propagation Delay
does the last bit get delivered?: T+P/R: Arrival time at B

P/R << T:

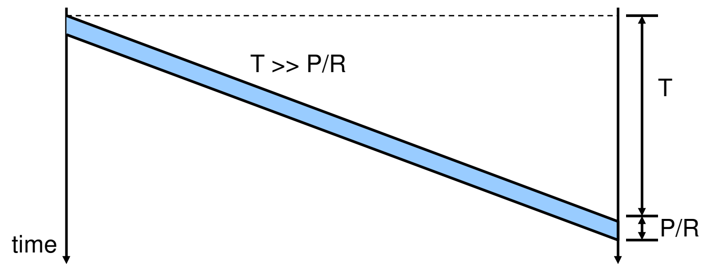


P/R >> T:

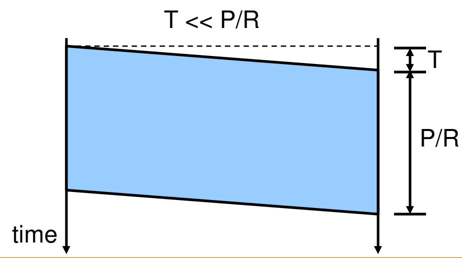


Timing Diagram

P = 1 Kbyte
R = 1 Gbps
100 Km, fiber =>
T = 500 usec
P/R = 8 usec

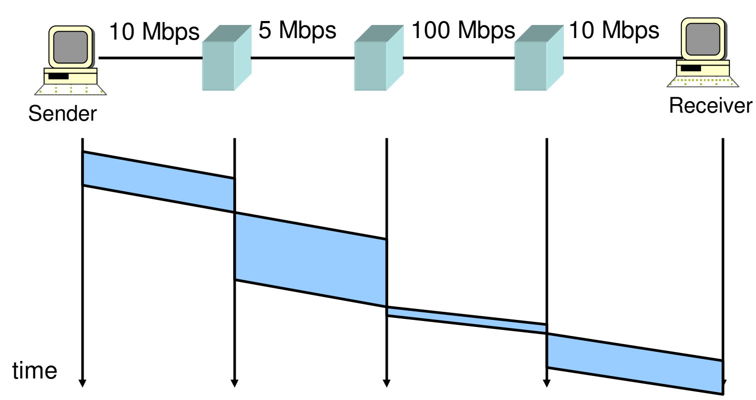


P = 1 Kbyte
R = 100 Mbps
1 Km, fiber =>
T = 5 usec
P/R = 80 usec



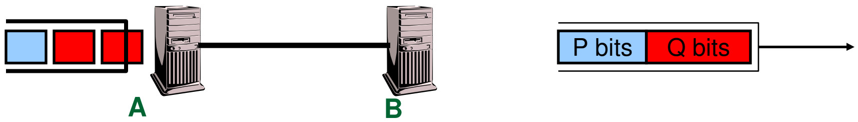
Switching: Store and Forward

- A packet is stored (enqueued) before being forwarded (sent)

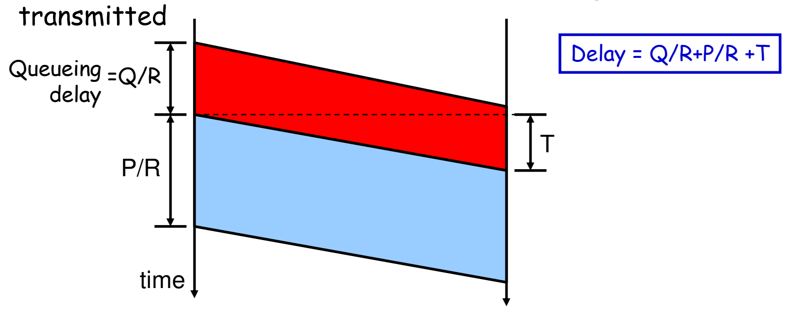


Queueing

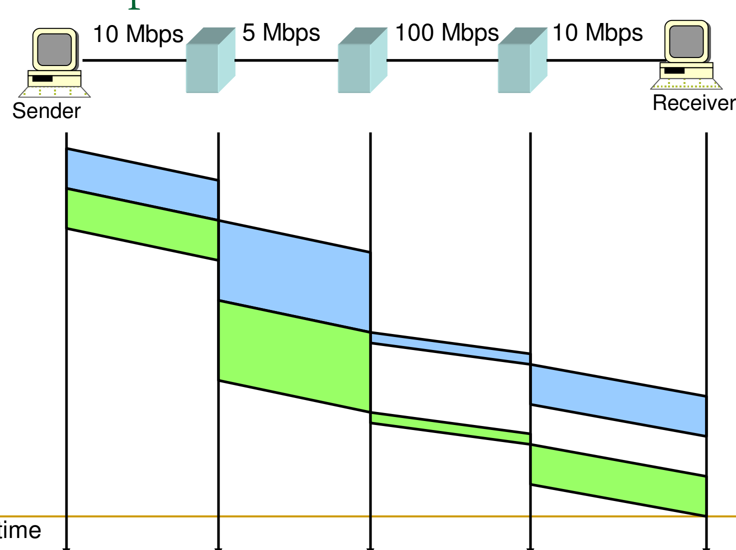
Packet Size: P bits
Link Speed/Bandwidth: R bps
Propagation delay: T sec



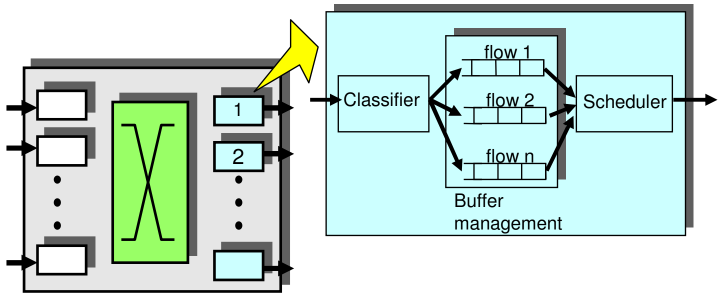
- The queue has Q bits when packet arrives → packet has to wait for the queue to drain before being transmitted



Store and Forward: Multiple Packet Example



Processing Delay



- Make sure packet has not been corrupted
- Forward to right output link queue
- Schedule the next packet to be transmitted from queue

Components of Per Hop Delay

- **Propagation delay:** time it takes the signal to t[ravel] from source to destination
- **Packet transmission time:** time it takes the sender to transmit all bits of the packet
- **Queuing delay:** time the packet need to wait before being transmitted because the queue was not empty when it arrived
- **Processing Time:** time it takes a router/switch to process the packet header, manage memory, etc

Only random component

Why Queueing Delay Confounds Performance Analysis

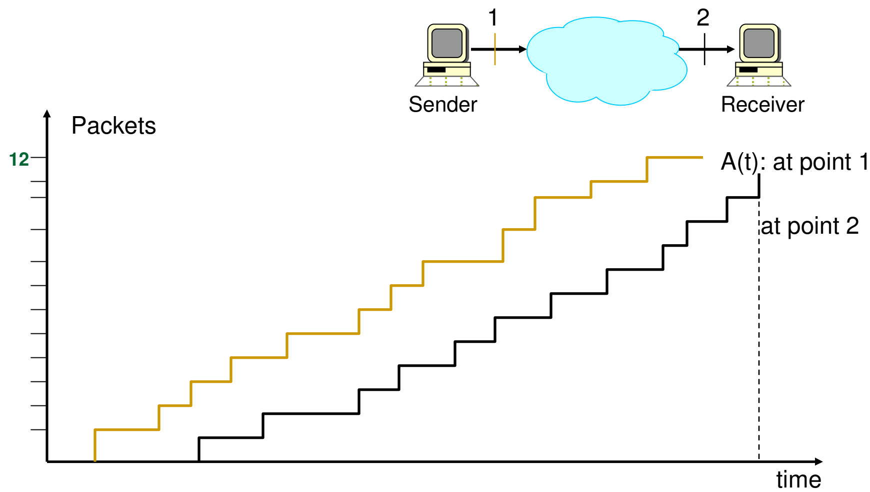
- Arrival processes are uncertain
- Modeled probabilistically
  - Analyzing a network of queues is very hard
  - Thousands of papers exist trying calculate measures of performance assuming specific arrival processes
- Simulated based on real data
  - Traces collected from actual network traffic
  - Drawing general conclusions from traces is very hard
- Good news: enough is known to be able to get many useful insights

Example

- Packets of average length P arrive at an average rate of a, where the arrival process follows a particularly nasty distribution
- The network consists of many hops over copper, fiber, satellite, undersea cable etc.
- There are many other contending sessions
- The average delay of a packet is D

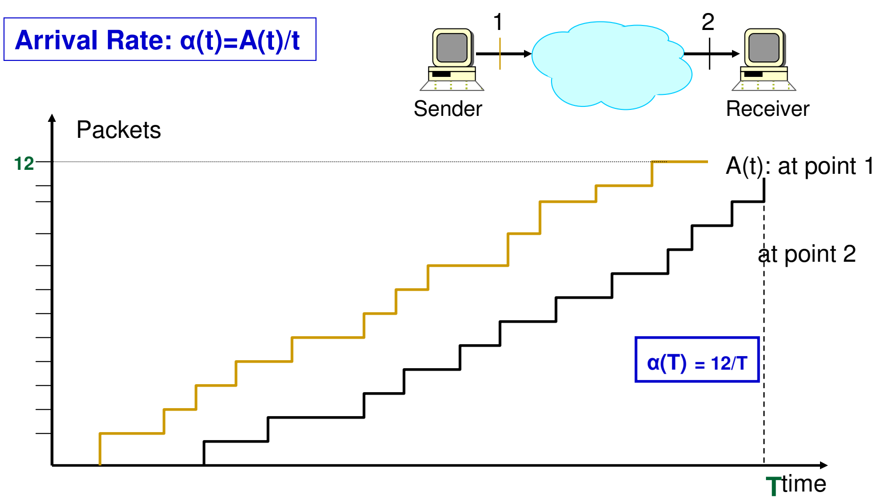
Question, how many packets are in the network on average?

Delays and Queues



Delays and Queues

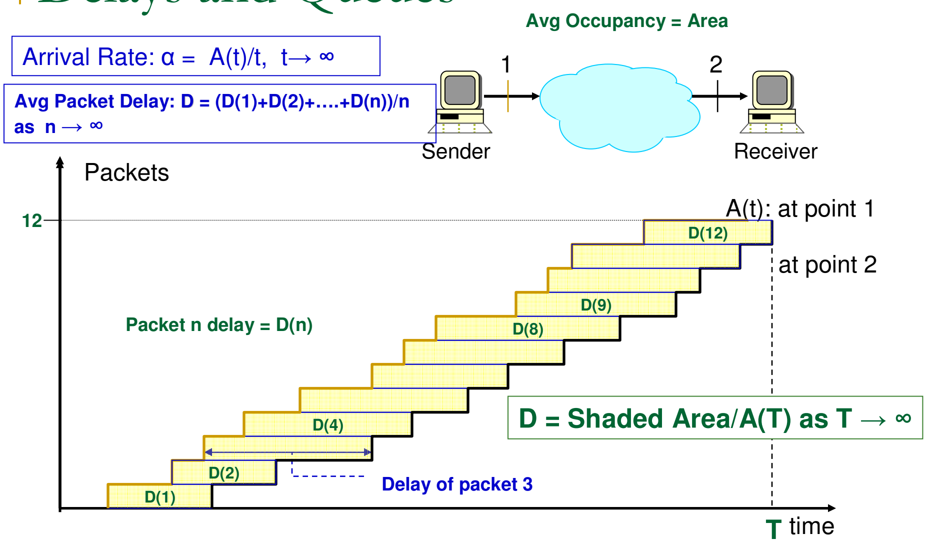
Arrival Rate: α(t)=A(t)/t



Delays and Queues

Arrival Rate: α = A(t)/t, t→ ∞

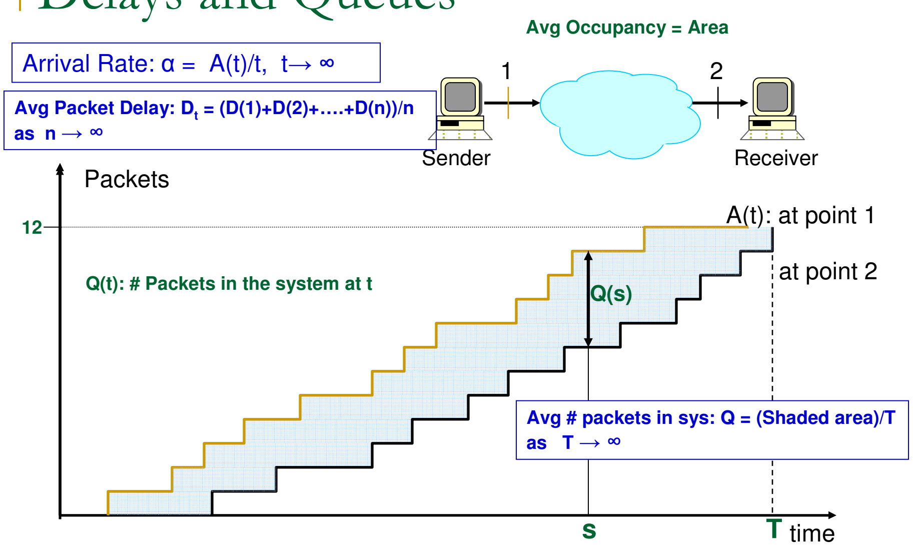
Avg Packet Delay: D = (D(1)+D(2)+….+D(n))/n as n → ∞



Delays and Queues

Arrival Rate: α = A(t)/t, t→ ∞

Avg Packet Delay: D_t = (D(1)+D(2)+….+D(n))/n as n → ∞



Little's Law

- Shade Area up to time T is equal to both

1. D(1)+D(2)+….+D(A(T))
2. $\int_0^T$ Q(t) dt

- Divide and multiple 1 by A(T):
  1. [D(1)+D(2)+….+D(A(T)) / A(T)] A(T)
- Divide both (rewritten) 1 and 2 by T and take limits
  - D α = Q

average occupancy = (average Delay) X (average arrival rate)

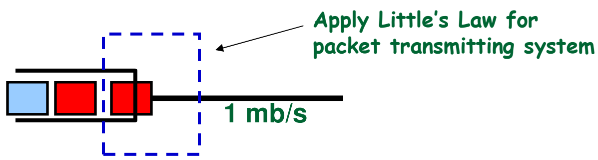
Little's Law

- Does Little's Law hold if:
  - the packet sizes are variable?
    - Yes
  - if the packets are not received in the order they are sent?
    - Yes
  - If there is loss in the system?
    - Depends

Application of Little's Law

- Suppose packets are of unequal length and the average length is 1000 bits
- The arrival rate of packets is 200 packets/sec
- R = 1 Mb/s
- What fraction of the time is the link busy?
  - This is defined as Link Utilization

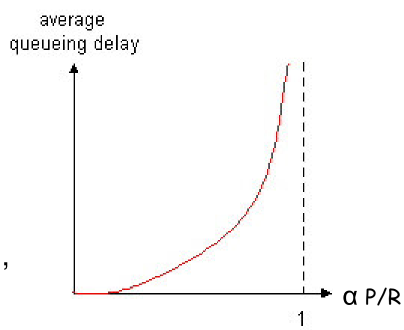
Application of Little's Law



- There can be 1 or 0 packets in the system
- α is still 200
- D = P/R = 1000/1000000= 1 millisecond
- By Little's Law utilization is α D = 0.2
- Link is idle 80% of the time

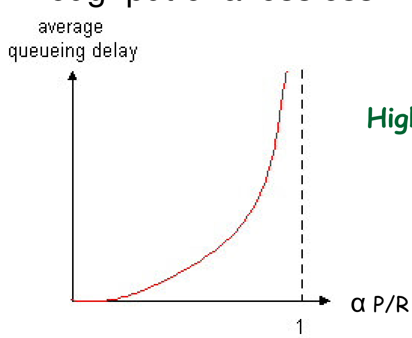
Utilization for a "typical queue"

- αP/R ~ 0: average queueing delay small
- α P/R → 1: delays become large
- α P/R > 1: more "work" arriving than can be serviced, average delay infinite!
- (The text refers to αP/R as traffic intensity)



Throughput

- The average number of bits successfully delivered per second.
  - Throughput of a lossless link: R X (Utilization)

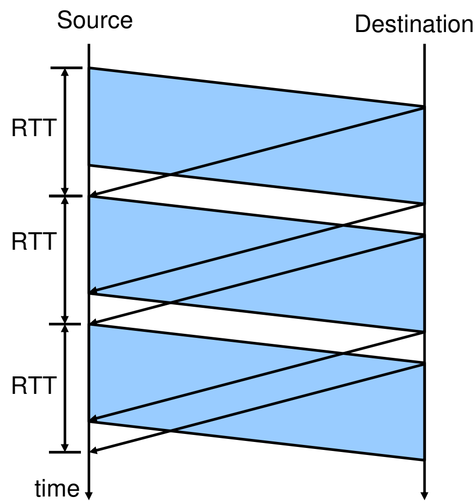


High Throughput, High Delay!

Example: Windows Based Flow Control

- Connection:
  - Send W bits (window size)
  - Wait for ACKs
  - Repeat
- Assume the round-trip-time is RTT seconds
- Throughput = W/RTT bps

- Numerical example:
  - W = 64 Kbytes
  - RTT = 200 ms
  - Throughput = W/T = 2.6 Mbps



What about broadcast networks?

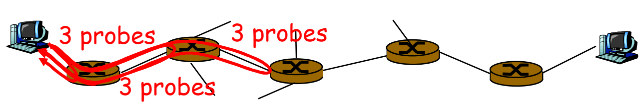
- There are n nodes sharing the broadcast channel
- When a node transmits a packet it collide with one from another node which has an overlapping transmission time
- Collisions can be detected by the sender
- What should a sender do upon detecting a collision?
- Throughput and delay depend heavily on scheme
  - Back off for a fixed time: very low throughput
  - Random back off time: better throughput
- More detail later…

Practical Matters

- Many mathematical queueing models are very difficult to analyze
  - Analysis makes often makes simplifying assumptions on A(t)
  - Analysis is hairy and incomprehensible to most
  - Analysis only works for toy problems
  - Mostly useful to generate insights
- A realistic network is very difficult to simulate
  - How do you know your improvement to Bittorrent is actually better?
- Measurements
  - gather data from a real network
  - realistic, specific
  - Victim of that particular network's design
- Simulations: run a program that pretends to be a real network
  - e.g., NS network simulator, Nachos OS simulator
- Usually use combination of methods

"Real" Internet delays and routes

- What do "real" Internet delay & loss look like?
- `Traceroute` program: provides delay measurement from source to router along end-end Internet path towards destination. For all *i:*
  - sends three packets that will reach router *i* on path towards destination
  - router *i* will return packets to sender
  - sender times interval between transmission and reply.



"Real" Internet delays and routes

traceroute: gaia.cs.umass.edu to www.eurecom.fr

Three delay measurements from gaia.cs.umass.edu to cs-gw.cs.umass.edu

```
1  cs-gw (128.119.240.254)  1 ms  1 ms  2 ms
2  border1-rt-fa5-1-0.gw.umass.edu (128.119.3.145)  1 ms  1 ms  2 ms
3  cht-vbns.gw.umass.edu (128.119.3.130)  6 ms 5 ms 5 ms
4  jn1-at1-0-0-19.wor.vbns.net (204.147.132.129)  16 ms 11 ms 13 ms
5  jn1-so7-0-0-0.wae.vbns.net (204.147.136.136)  21 ms 18 ms 18 ms
6  abilene-vbns.abilene.ucaid.edu (198.32.11.9)  22 ms  18 ms  22 ms
7  nycm-wash.abilene.ucaid.edu (198.32.8.46)  22 ms  22 ms  22 ms
8  62.40.103.253 (62.40.103.253)  104 ms 109 ms 106 ms
9  de2-1.de1.de.geant.net (62.40.96.129)  109 ms 102 ms 104 ms
10  de.fr1.fr.geant.net (62.40.96.50)  113 ms 121 ms 114 ms
11  renater-gw.fr1.fr.geant.net (62.40.103.54)  112 ms  114 ms  112 ms
12  nio-n2.cssi.renater.fr (193.51.206.13)  111 ms  114 ms  116 ms
13  nice.cssi.renater.fr (195.220.98.102)  123 ms  125 ms  124 ms
14  r3t2-nice.cssi.renater.fr (195.220.98.110)  126 ms  126 ms  124 ms
15  eurecom-valbonne.r3t2.ft.net (193.48.50.54)  135 ms  128 ms  133 ms
16  194.214.211.25 (194.214.211.25)  126 ms  128 ms  126 ms
17  * * *
18  * * *
19  fantasia.eurecom.fr (193.55.113.142)  132 ms  128 ms  136 ms
```

trans-oceanic link

* means no response (probe lost, router not replying)

What we learned

- How to think of the internet as a network of queues
- The components of delay
- Little's Law
- Utilization
- Simple examples of throughput
  - Link, TCP connection, broadcast network
- Measuring delays